Spatial connectivity and distribution of landscape type in the natural secondary forests of eastern mountainous region, northeast China----a case study of Mao'ershan region in Heilongjiang Province

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Abstract: Mao'ershan region is representative in the natural secondary forested region of the eastern mountainous region, northeast China. The landscape nearest neighbor index and landscape connectivity index were calculated with ARC/INFO software for Mao'ershan region. The spatial distribution of the landscape of the region was analyzed. The results showed that the landscape connectivity index of non-woodland was significantly higher than that of woodland. The landscape connectivity index of natural forest was nearly equal to zero, which means its fragmentation degree is high. The nearest neighbor index of plantation was lower than that of natural forest and non-forestland. Among the man-made forests, the distance index of the coniferous mixed plantation is the lowest, and its pattern is nearly glomeration. The landscape pattern of natural forest presented nearly random distribution. Among non-forest land, the distance index of cut blank was the lowest, and its pattern was also nearly glomeration.

Keywords: Landscape type; Landscape pattern; Nearest neighbor index; Landscape connectivity index; Natural secondary forest; Northeast China

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Introduction

Landscape pattern is the result of long-term effects of biotic and abiotic processes in a region. At the same time, the landscape pattern has direct and indirect influences on the biotic and abiotic processes. Only when we understand the characters of regional landscape, we could provide the scientific basis for the rational management and utilization of regional resources (Yue *et al.* 1997). In the analysis of landscape pattern, not only the shape, size and type of patches but also the adjacency and spatial distribution of landscape pattern should be taken into account, because of the characters of landscape heterogeneity and the complex of patch combination (Chang *et al.* 1998). Therefore, how to find out the spatial distribution of landscape types in the complex mosaic of patches became one of the key issues in the research of landscape pattern (Ma *et al.* 2000). The spatial distance and the landscape connectivity are important indices for describing the distribution and interrelation of landscape elements.

The landscape connectivity was one of the main studying contents of landscape ecology (Dunning *et al.*1992; Taylor 1996), which was firstly applied in landscape ecology by Merriam in 1984. It is regarded as an index reflecting the ecological processes of landscape. Through such ecological processes, the subpopulations in the landscape became an organ entity by interacting. Forman and Godron (1986) pointed out that the landscape connectivity was a measure linking or continuing the carriage or matrix of landscape in space. There are many different definitions to connectivity, but all the definitions imply that the connectivity is to describe the phenomena of interaction and interrelation among the landscape units (Mcdonnell *et al.* 1988). Many researches showed that the landscape connectivity had an important function in conserving the habitat of propagation and the species in fragmental landscape (e.g. the strong disturbed agricultural region by human activities), (Forman *et al.* 1984; Wu *et al.* 1993). The magnitude of landscape connectivity depended on the characters of landscape structure (Merriam 1988; Merriam 1991). The landscape structure determines the function and change of landscape. On the other hand, the evolvement of landscape structure could arouse new configuration and function of landscape. Ecologists generally adopted the method of studying pattern of landscape elements in space to reflect the different ecological function and process of landscape due to the fact that the activities of surveying ecological function and process could exhaust much force and longer time (Turner 1989). Therefore, it is necessary to

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study the landscape space structure during the research of landscape connectivity.

Nearly all the forests belong to the natural secondary forest in the northeast of China. Mao'ershan region is representative in the natural secondary forested region of the eastern mountainous region, northeast China. These secondary forests were gradually formed by secondary succession on the secondary bare areas, where was occupied by the primary forest vegetation of broad-leaved/Korean pine forest several hundred years ago (Chen *et al.* 1994). Along with the deepening recognition to forest structure and function as well as the intensification in forest management, it is necessary to analyze the spatial pattern of landscapes in the natural secondary forested region. Based on the spatial distance of patches and the support of GIS, the spatial interrelation of landscape elements for Mao'ershan region was calculated by adopting nearest neighbor index and landscape connectivity. In this paper, the spatial distribution of landscape elements was found and the forming mechanism of regional landscape was revealed. This is an important approach in landscape pattern analysis, which has an important effect on landscape ecology research. At the same time, the study can offer some rational references in conserving biodiversity, landscape layout and management.

Study areas

The study area is located at the Mao'ershan Experimental Forest Farm of Northeast Forestry University, at latitude of 45°20'-45°25' N and longitude of 127°30'-127°34' E, 108 km far away from Herbin The topography becomes gradually higher from south to north. Average slope degree is 10°-15°. The climate is terrestrial monsoon. Annual average rainfall is 723.8 mm, with about 54% in July and August. Plants belong to Changbai Mountains vegetation. The main communities are *Quercus mongolica* Fisch. ex *Ledeb* forest, *Populus davidiana* forest, *Betula platuphylla* forest, *Juglans mandshurica* forest, *Fraxinus mandshurica* forest, fen and wetland. The typical mountain soil is dark brown forest soil. There are other soil types including albicans soil, meadow soil, and mire soil in the hill below 300 m.

Methods

Patch classification

The classification of patches as an element in a landscape should firstly be resolved during the study of landscape pattern. According to utilizing status and management purpose in the Mao'ershan region, the 2-grade classification was adopted to reflect the landscape characters. First grade: According to utilizing soil status, patches were classified into forestland and non-forestland. Forestland is the area where the vegetation covering degree is ≥0.2 in arboreal layer, while Non-forestland is the area where the vegetation covering degree is less than 0.2 in arboreal layer, including the land not for forestry objective. Second grade: Based on the first grade, according to patch appearance, patch occurring, patch originating, dominant tree species, and soil utilizing status, the patches were sub-classified into Korean pine plantation, larch plantation, Mongolian oak plantation, broad-leaved and conifer mixed plantation, broad-leaved and conifer forest, hardwood broad-leaved forest, softwood broad-leaved forest, nursery, wetland, paddy field, cropland, badland, deforested land, and wasteland.

Distance index of landscape

Based on the forest type map (1:10000) that was drawn by combining aerial photographs of 1999 and ground investigation, topography map of 1993 (1:10000), and soil utilization map of 1999 (1:10000), the landscape patch distribution plot combined spatial data and attributive date was drawn under the support of GIS. The patch number, area, and the distance between patches were also drawn.

The distance between patches indicates the distance between the similar patches. The distance index constructed with the distance between patches has two usages: one is used to estimate whether the distribution of patches in landscape is random distribution, the other is used to quantify the degree of connectivity or isolation for patches in a landscape (Li 1992). There are two kinds of distance indices, such as the nearest neighbor index and the connectivity index.

Nearest neighbor index

Clark and Evans (1954) used the nearest neighbor index to verify whether the distribution of individuals in a population is random. The distance between patches in this article replaced the distance between species in the Equation (1).

$$N_{\mathrm{NI}} = M_{\mathrm{MND}} / E_{\mathrm{NND}} \tag{1}$$

where, N_{NI} is the nearest neighbor index, M_{NND} is mean minimum distance between the patch and its nearest neighbor patch, E_{NND} is Expectative value under the presupposition of random distribution of patch. M_{NND} and E_{NND} were calculated with the following equations.

$$M_{\mathrm{NND}} = \sum_{i-1}^{N} N_{\mathrm{ND}}(i) / N \tag{2}$$

$$E_{\mathrm{NND}} = 1/(2\sqrt{d}) \tag{3}$$

where, N_{ND} (i) is the nearest neighbor distance between patch i and its nearest neighbor patch; d is the density of the calculated patch in a landscape; N is the patch number of the calculated patch type.

In N_{ND} (i), the distance was length between the centers of patch i and the center of its nearest patch. Because the shape of patch was irregular, it was difficult to define the

center of patch. So the gravity center was used to replace the center of patch. The formula of the patch-density was as follows:

$$d = N / A \tag{4}$$

where, A is the total area of landscape; N is the patch number of the calculated patch type.

If N_{NI} is 0, the pattern is a full mass distribution; If N_{NI} is 1.0, the pattern is a random distribution; If N_{NI} is 2.149, the pattern is a full regular distribution (Li 1992; Wu 2000).

Connectivity index

The connectivity index of landscape indicated the degree of succession of landscape, and the potential of correlation between the patches in ecological function and ecological process (Guo 2001). The connectivity index is the contact extent of the same type patches in landscape, and has the anti-function of the nearest neighbor patch distance, which uses the surface area of the patch as weight.

$$P_X = \sum_{i=1}^{N} \frac{A(i)/N_{NND}(i)}{\sum_{i-1}^{N} A(i)/N_{NND}(i)} \tag{5}$$

In Equation (5), P_X is the connectivity index; A (i) is the surface area of the patch (i); N_{ND} (i) is the minimum distance between patch i and its nearest neighbor patch. P_X get value from 0 to 1, when P_X is maximum, it means that the given patch type in landscape woodland is clustering (Li 1992; Wu 2000).

Results and analysis

Analysis of the nearest distance index

The patch number of each landscape type, area and the distance between the patches belonging to the same landscape type was calculated with software of STATICTICS and ARC/INFO. The nearest distance index was calculated according to the equations (1), (2) and (3). The results showed that the distance index of coniferous mixed plantation in plantations was smaller and its pattern was nearly clustering, which means the area with less planted plantation and lower density (Fig. 1). With the supposition of random distribution, the expected value of the average nearest distance is larger. From the equation of nearest distance, the differences of distances between patch and its nearest neighbor patch were smaller. The larger the expected value is, the smaller the nearest distance index is, and its pattern was nearly clustering distribution. The nearest distance index of hardwood broad-leaved forest and coniferous and broad-leaved mixed forest was nearly equal to 1, and their pattern was close to random distribution. The proportion of softwood forest in all forests was largest, and its number of patch was the most. The patches were dispersal and the distance index of the patches was larger. But patches still were close to random distribution. The distance index of deforested scar was the smallest in non-forestlands, and pattern was close to mass distribution. The distribution of swampland was more clustering, and its distance index was smaller. In general, as the plantation distribution was regular and concentrative, the distance index of plantations was smaller than that of natural forests and non-forestland.

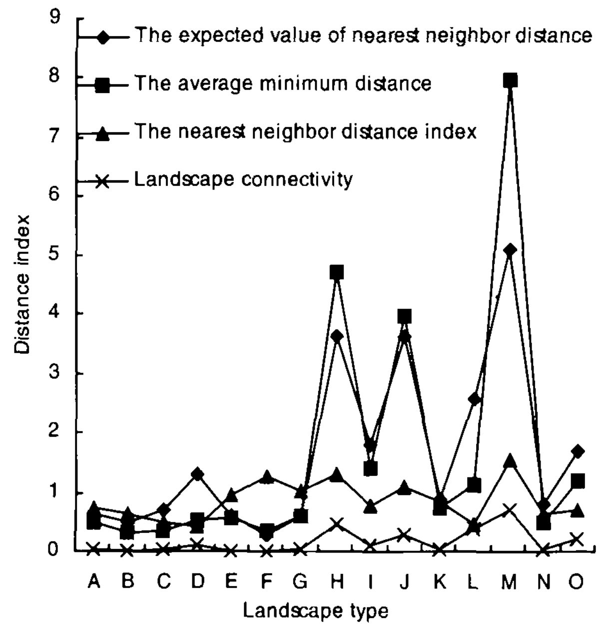

Fig. 1 Nearest neighbor distance index of main landscape woodland for Mao'ershan region

A----Korean pine plantation; B----Larch plantation; C----mongolian scotch pine plantation; D----coniferous mixed plantation; E----hardwood broad-leaved forest; F----Softwood broad-leaved forest; G----coniferous and broad-leaved mixed forest; H----nursery; I----Cropland; J----irrigated land; K----barren hill and wasteland; L----deforested land; M----wasteland suited for forest; N----swampland; O----others.

Analysis of landscape connectivity

Based on the analysis of patch area and the nearest neighbor of patches, the index of landscape connectivity was calculated by adopting the Equation (5). The results were shown in Fig. 2. The comprehensive analysis of landscape connectivity index for different landscape types showed that the landscape connectivity index of non-forestland was larger than that of forestland. The man-controlled landscapes, such as nursery, deforested scars, etc. are concentrated distribution types. Their connectivity indices were higher, and distribution types were close to mass distribution. Because the coniferous mixed plantation was concentrative distribution and it was a few affected by human disturbance, its connectivity index of in plantations was larger. The connectivity index of Korean pine plantation, larch plantation and Scotch pine plantation was smaller. The landscape connectivity index of natural forest was nearly to 0.

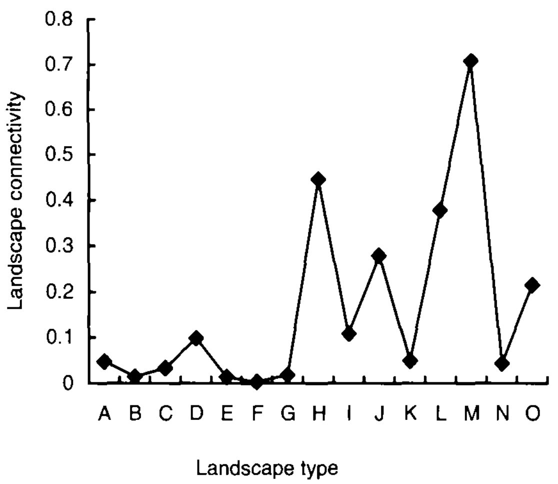

Fig. 2 Degree of landscape connectivity of main landscape woodland in Mao'ershan region

A----Korean pine plantation; B----Larch plantation; C----scotch pine plantation; D----coniferous mixed plantation; E----hardwood broad-leaved forest; F----Softwood broad-leaved forest; G----coniferous and broad-leaved mixed forest; H----nursery; I----Cropland; J----irrigated land; K----barren hill and wasteland; L----deforested land; M----wasteland suited for forest; N-swampland; O-else.

Conclusions and discussion

With the supposition of random distribution, the amount of patches is less. The expected value of average nearest neighbor distance between the patch and its nearest neighbor patch was larger. When the real nearest distances between the patch and its nearest neighbor were nearly equal, the nearest distance index of landscape is smaller.

The distance index of plantation was lower than that of natural forest and non-forestland because of the plantation's regularity and concentration distribution. Therefore, the pattern of plantation is nearly mass distribution. The landscape pattern of natural forest is close to random distribution.

Although the landscape pattern of hardwood broad-leaved forest and coniferous and broad-leaved mixed forest is close to random distribution, these populations of hardwood broad-leaved forest and coniferous and broad-leaved mixed forest are all developing populations, and the patches are on the expanding stage, whose patches have chance to gradually expand from margin.

Some pioneer forestry community in hardwood broad-leaved forest will gently form dispersedly small patches in initial stage of succession, and the expanding ability for far distance in spatial is strong. With the evolvement of the process of succession, some pioneer population (such as poplar) gradually changes into declined population. When the patches succession or replacement happens, the patch area is further compacted.

The degree of landscape connectivity for non-woodland was larger than that of woodland. On the one hand, there many new patches occur with the updating of forest. These continually expanding patches make the original patches be divided and eroded, which leads the degree of patches fragmentation become larger and the degree of landscape connectivity become small. On the other hand, this shows those landscape woodland have been largely disturbed by human. The original large landscape woodland was divided into small patches, the degree of fragmentation was large, and the degree of landscape connectivity was small.

In non-woodland, the higher the landscape connectivity was, the higher the nearest distance index was. We can conclude that the nearest distance index only reflects the distribute characteristics of the patch center point in landscape woodland, but it couldn't reflect the interrelation of landscape patches, especially when the area of patch has large change, and the error would be larger.

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